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ABSTRACT

This document focuses on using satellite images from space in the classroom. There are two types of environmental satellites routinely broadcasting: (1) Polar-Orbiting Operational Environmental Satellites (POES), and (2) Geostationary Operational Environmental Satellites (GOES). Imaging and visualization techniques provide students with a better understanding of Earth science and develop thinking skills. Classroom use of images from space include student activities using image orientation and image analysis. The appendix contains images of the earth and figures of satellite orbit and positioning. (Contains 17 references.) (YDS)

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Satellite Imaging in

Pennsylvania's

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Satellite Imaging in the Study of Pennsylvania's Environmental Issues

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The computer's high-resolution display of screen images provides a new palette for the brush strokes of one's mind. Space "pictures" arrive as shuttle, satellite, and computer-generated images. Imaging is distinguished as the acquisition, enhancement, re-representation, and re-distribution of a graphic for analysis and reporting. Visualization is distinguished as the representation of data using software tools. Imaging and visualization changes our orientation and focus in problem solving and students have many opportunities for image analysis of Earth and the solar system (Martin, 1977; Tindal, 1978). From these opportunities, students "can better understand key concepts in Earth science; develop skills of scientific thinking and problem solving; and conduct their own Earth investigations (Barstow, 1997; 1998)." But how do students, and teachers, develop this understanding? After all, image analysis is an extremely intense cognitive exercise! How does one build time for analysis into the curriculum? How will the advances of imaging from remote sensing find their way into the curriculum, which also must advance? Yet imaging and visualization in the sciences has not impacted the science curriculum for the majority of grade K-12 students. Students may encounter this technology in medical imaging, neuroscience, pollution studies, and weather mapping, but never fully come to appreciate the development, analysis, or discussion of such representations in their science curricula. In addition to ancestral, long-term, and short-term memory, there is the delineation of eidetic, popularly called photographic, memory. Eidetic memory, not usually promoted in school involves extraordinary, vivid, and accurate recall, especially of visual images, and may be "schooled out" of our children in elementary school.

While the words "picture" and "satellite data" appear in Earth space science and science and technology sections, the National Science Education Standards make no mention of "images," "graphics," and "visualization." The term "computer" is used twice in the Guide to the Content Standards section dealing with abilities necessary to do scientific inquiry. Computing is covered in two paragraphs, in grades 5 to 8 under the standards "use appropriate tools and techniques, to gather, analyze, and interpret data" and, in grades 9-12, "uses technology and mathematics to improve investigations and communications" (National Research Council, 1996). Benchmarks of the American Association for the Advancement of Science (1993) provide grade-level expectations of student competencies, none of which involve imaging and visualization. The recent Blueprints for Reform (1998) gives token references to the Internet and sees computer use in schools as a prelude to workforce entry and maintenance. Generally speaking, the picture is bleak if standards are to rush us urgently into using imaging and visualization in the classroom. Organizations provide standards, government and industry provide the technology, but it will be up to the educators to infuse this technology into the classroom.

Mayer (1995) reports that instruction to acquaint students with earth system concepts and processes is practically non-existent. While not discussing the efficacy of the standards in curriculum reform, Mayer points to imaging and visualization as a powerful instructional tool still in its early phases of curricular infusion in the science education setting. But, it has been reported also "Visualizations allow the teaching of subject material not ordinarily taught, and allow it to be taught earlier in the curriculum" ("Graphics and visualization," 1995). Why this discrepancy in viewpoints? Mathewson (1999) criticizes current practice in education because it places visual-spatial thinking in a subservient role with the dominance of the alphanumeric encoding skills in classroom activity and textbooks.

Despite modern-day computer capabilities, imaging and visualization research depends primarily upon the individual's ability to recognize patterns in the data. The goal of the National Aeronautics and Space Administration (NASA) is to expand its research agenda toward understanding the Earth as a system, the origin of the universe, and its path in evolution. With the increase of collaborative missions exploring space phenomena there is a concomitant increase in the amount of visual data received from earth and space observing satellites. Such images require rigorous analysis and interpretation that leads to meaningful scientific, policy and values insight. There is a widely distributed research community with access and ability to manipulate tools that analyze and visualize data (visit www.pitt.edu/~nasa for web access).

THE TECHNOLOGY

State, federal and international governments, meteorological and environmental management organizations, universities, bush-fire control centers, marine and harbor corporations, international airports, and agricultural spraying contractors currently use satellite systems. The deployment of satellites is an international venture. Environmental satellites routinely broadcast two types of low-resolution images, Automatic Picture Transmission (APT) images from Polar-orbiting Operational Environmental Satellites (POES), and Weather Facsimile (WEFAX) images from Geostationary Operational Environmental Satellites (GOES). Acquiring images from space can also be accomplished using space-borne imaging radar - Synthetic Aperture Radar (SIR-C/X-SAR) technology. A complete glossary of terms and bibliography related to remote sensing and direct readout in the Earth Science enterprise, formerly called Mission to Planet Earth, is available in hardcopy form (NASA, August 1994). Besides manned space flight and interplanetary exploration, NASA also had the charter to advance the state-of-the-art for spacecraft design and applications, space science studies, and earth application satellites. In the early 1960s, NASA began weather reporting by developing the medium orbit Television and Infrared Observation Satellite (TIROS), and the polar orbit more advanced Nimbus spacecraft. It continued with earth studies using the Explorer series of satellites. To advance satellite technology, NASA orbited the Syncom group of satellites, which were the first communication spacecraft, put into geosynchronous orbit, and the Applications Technology Satellites (ATS) to pushed the state-of-the art for communications satellites. In the 1970s, NASA established continued developing weather satellites with the Improved TIROS Operational Satellites (ITOS), and eventually turned over day-to-day operations to the National Oceanographic and Atmospheric Administration (NOAA). In the mid 70s, NASA designed the Synchronous Meteorological Satellites (SMS) that evolved in the Geostationary Environmental Operational Satellites (GEOS), which are also handled by NOAA. Our present day TV weather reports are provided by the GEOS system. Finally, a new applications satellite was tested to perform earth remote sensing, and was initially called the Earth Resources Technology Satellite (ERTS). It was later renamed LANDSAT.

a. Polar Orbiters

Currently there are two United States, fully functional, POES weather satellites, NOAA 12 and 14. There are defense-related weather satellites that NOAA will take over by the year 2000 as a federal cost cutting measure (Orbis Technology, 1997). Russia operates Meteor 2-21 and 3-5 satellites that also transmit WEFAX. Russia also operates OKEAN satellites that transmit WEFAX but are nearly always turned off, except when over Russian territory.

NOAA polar satellites orbit the earth about 14 times per day with orbits inclined about 98 degrees to the equator in a retrograde or east-to-west orbit while the earth spins west to east. The advantage to this particular orbit is that satellites cover the same part of the earth at approximately the same time, each day, for the life of the satellite. Called a sun-synchronous orbit, it continuously scans the earth directly below, its subsatellite point, with its sensors and transmits this data whenever it passes within range of an environmental satellite ground station. Each scan's coverage slightly overlaps the last.

Figure 1 goes here

An APT-equipped satellite makes real-time reception of satellite images with high definition of surface features in low earth polar orbit, approximately 1,000 km above the earth, and travels at a ground speed of approximately 25,000-km per hour. In each 24-hour period, a satellite sends several images, clearly showing current location conditions and future events heading its way. These simultaneous thermal IR and visible images cover swaths 3000-km wide, yield 4-km picture elements (pixel) resolution, and the capability for image enhancement. Infrared sensors actually measure temperature rather than reflected light as in visible satellite images. In an infrared picture, warmer objects appear darker than colder objects, as in figure 2, which is constructed as you see it here for comparison only. The satellite image marked "visible" shows cloud cover where areas of white indicate clouds and shades of gray indicate generally clear skies. Since temperature in the troposphere decreases with height, high-level clouds are colder than low-level clouds. Therefore, in figure two, low clouds (as found over North Carolina and Virginia) appear darker on an infrared image and higher clouds (as found throughout the eastern U.S.) appear brighter.

Figure 2 goes here

Each NOAA image is sent showing two side-by-side IR and visible images of the same area of the earth's surface. When the satellite is passing over an area illuminated by the Sun, one image is in visible light, the other in infrared (IR). When the satellite is passing over an area not illuminated by the Sun, the visible light image switches to IR in another part of the spectrum. Costs for an APT ground reception station run approximately $2000, excluding the computer (NASA, January 1994).

b. Geostationary Orbiters

NOAA WEFAX transmissions are relayed by GOES that follow the spin of the Earth from 36,200 km in space. Currently the U. S. operates two geostationary satellites (GOES-8 and -9) in orbit over the equator. Another such satellite system is the Japanese GMS 5, which is 36,000 km above the earth and is always stationed over the same point on the earth's surface. Due to the distant location of geostationary satellites, image detail and definition are generally reduced when compared to those of Polar orbiters. However these images can be animated, making it very easy to track cloud formation and movement, especially when tracking cyclones and hurricanes. WEFAX then retransmits, by radio waves, the modified data as visual reproductions of weather forecast maps, temperature summaries, and cloud analysis that you see on the evening weather forecast. WEFAX allows for hemispheric coverage, 8 km pixel resolution, images at thermal IR, visible, and water vapor lengths, new weather maps, image animation, diagrams, and images, hourly from unattended and automatic ground station operation.

Figure 3 goes here

There are both land- and marine-based APT and WEFAX satellite systems that assist in decision making for weather-dependent activities. Marine-based satellite images are ideal for marine and mobile activities such as sea fishing, commercial shipping, ferried and cruise liners, sailing, gas and oilrig operations, Coast Guard services, yacht racing, diving operations, and leisure activities. For example, *Weather Avoidance Routing* identifies various best routes around undesirable weather. Again, referring to figure 2, clouds are visible on both versions of the image but, since fog is similar in temperature to the sea surface, it does not show up on the infrared version. Fog banks are clearly visible on the visible light version, allowing a route to be planned, which avoids the fog. Coloring the parts whose temperatures lie within a specified range can clearly show *Temperature Boundary Highlighting* between warm and cool areas in an image. With latitude, longitude and temperature along these boundaries identified, the types and quantities of fish surfacing to feed can be identified and areas of good fishing can be determined easily. Once a day, at about 1600 Universal Coordinated Time (UTC), a composite image is produced from the above three-hourly sea surface temperature (SST) images. The warmest SST value at any location is retained; persistent clouds remain in black. The geostationary perspective provides frequent viewing, which permits improved spatial coverage with time, as clouds move in and out of any particular region.

Figure 4 goes here

USING IMAGES FROM SPACE

Images from space are a delight to the mind! But how do we use them in the classroom? To introduce students to image analysis, begin with the student's perception, usually ground-based then proceed to the uncommon image views provided by satellites. Let me take a few examples from the on-line Remote Sensing Tutorial (1997). I am indebted to Dr. Nicholas M. Short, Sr., and the Applied Information Science Branch (Code 935) at NASA's Goddard Space Flight Center, for the on-line Remote Sensing tutorial approach for learning about the role of space science and technology in monitoring the Earth's surface and atmosphere. This is monumental work involving interagency collaboration available on the World Wide Web (http://rst.gsfc.nasa.gov).

The image orientation and image analysis activities follow a progression from the student's everyday orientation…the ground to the aerial photograph. With mapping skills, orientation is the first task. The teacher extrapolates from the flat perspective of the map to that of the shuttle or satellite image. One-to-one matching of maps or pictorial representations with actual shuttle images is a beginning logical operation of classification. Eventually students then become interested in either the method by which a satellite "tracks" the earth's surface or begins exploring a particular environmental problem when comparing images of the same location. The utilization of images in science education opens opportunities to develop a multidisciplinary curriculum in which science and social science complement each other in addition to the traditional science-mathematics connection.

MATCHING TECHNOLOGY TO ENVIRONMENTAL ISSUES

The Commonwealth of Pennsylvania is unique in its landform and ecological interactions. It is most important that technology not be seen as the only component used in the study of environmental issues. Technology and human resources must be used because while technology "gathers data" it is usually the researcher that "interprets" the data and values the implications. The first step is to identify the issues playing a major role in Pennsylvania's ecological constitution. Such issues are:

- Watersheds and Wetlands
- Renewable and Nonrenewable Resources
- Environmental Health
- Agriculture and Society
- Integrated Pest Management
- Ecosystems Interactions
- Threatened, Endangered and Extinct Species
- Human Impacts

Remote sensing involves the use of instruments or sensors to "capture" the spectral and spatial relations of objects and materials observable at a distance - typically from above them. So the next step is to consider the spectral and spatial configurations associated with phenomena in each issue. Most recently I was struck by the wealth of information available within our own State's Academic standards for Environment and Ecology. As such the Standards become, not only a guide for curricular reform, but also a resource from which data in this second step may be delineated. For example in Standard 4.1.10 A, "Identify Pennsylvania's major watersheds and their related river systems." Or "Describe changes by tracing a specific river's origin back to its headwaters including its major tributaries." In another Standard 4.5.7 A, "Identify several locations where pests can be found and compare the effects the pests have on each location." This study might relate to using remote sensing images used to map the study area and to help determine environmental factors that may influence the abundance of organisms from sand flies to the vectors of West Nile Fever.

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A computer assembles image data received from satellites, which recreates the scene by arranging pixels into columns and rows with a different hue assigned to each pixel number. This is called Image processing. Shades of gray and colors organized into columns and rows are "seen" but the individual pixels are not unless magnified. If the image's colors are the same as if seen with the human eye then it is a "true color" image. If the image's true colors are made to look different, then it is a "false color" image. Believe it or not, false color images sharpen the demarcation and detail of objects and features in images. The image is certainly more interesting to examine. Another reason for "false color" image use is that our eyes can detect about 30 shades of gray but can distinguish about 100 colors in the ROYGBIV visible spectrum.

The next steps in the analysis are locating, identifying, and measuring features, and determining scale. Eventually, the determination of area is important to get some sense of the magnitude of the feature. Sometimes analysts trace the "footprint" of the feature of the image onto transparencies for eventual coding, or classification, of land or water use. The following table is a sample signature key for LANDSAT false-color images (Coyle, Shapiro, & Stroud, 2000; p. 137):

Table 1 goes here

A sample image, with explanation, is provided in Appendix A of the Remote Sensing turorial (NASA, 1997). It is taken from Section 3: Vegetation Applications – Agriculture, forestry, and Ecology covering defoliation and mine wastes.

GROUND TRUTH

In remote sensing, ground truth is on- or near-surface observations. Ground truth ultimately aids in the calibration and interpretation of remotely recorded surveys by checking out realities from the scene. Human interpreters normally experience the Earth as ground dwellers. Their view of the world from a horizontal or low-angle panorama is the customary frame of reference. "In fact, both the remote sensing specialist and the novice should retain a surface-based perspective during all phases of data collection, analysis, and applications inasmuch as most interpretations and decisions dealing with natural resources and land use will eventually be implemented at the ground level (NASA, 1997)."

Among the ground-oriented data sources one can find field observations, in situ spectral measurements, aerial reconnaissance and photography, descriptive reports and inventory tallies, and maps. The types of tasks and operations associated with obtaining and utilizing ground truth are to:

- Correlate surface features and localities, as seen from familiar ground perspectives, with their expression in satellite imagery;
- Provide input and control during planning for analysis, interpretation, and application of remote sensing data;
- Reduce data and sampling requirements (e.g., areas of needed coverage) for exploration, monitoring, and inventory activities;
- Select test areas for aircraft and other multistage support missions (e.g., under flights simultaneous with spacecraft passes);
- Select and categorize training sites for supervised classification;
- Verify accuracy of classification (error types and rates) by using quantitative statistical techniques;
- Obtain quantitative estimates relevant to class distributions (e.g. field size; forest acreage);
- Collect physical samples for laboratory analysis of phenomena detected from remote sensing data (e.g., water quality; rock types; insect-induced disease);
- Acquire supplementary (ancillary) non-remote sensing data for interpretive model analysis or for integration into Geographic Information Systems;
- Develop standard sets of spectral signatures by using ground-based instruments; and
- Measure spectral and other physical properties needed to stipulate characteristics and parameters pertinent to designing new sensor systems (NASA, 1997).

Typical observations and measurements conducted in the field, commonly as the remote sensing platform is passing over, or shortly thereafter, include meteorological conditions (air temperature, wind velocity, humidity), insolation (solar irradiance), on-site calibration of reflectance, soil moisture, water levels (stream gauge data), snow thickness, silt deposition in lakes and rivers, growth stages of vegetation, distribution of urban subclasses, and soil and rock types.

> Ground truth activities are an integral part of the "multi" approach. Thus, data should be procured whenever possible from different platforms (multistage), at various distances from Earth's surface (multilevel). This gives rise to multiscaled images or classification maps. Multisensor systems should be employed simultaneously to provide data over various regions of the spectrum (multispectral). The data must often be obtained at different times (mutitemporal), whenever seasonal effects or illumination differences are factors or change detection is the objective. Supporting ground observations should come from many relevant, but not necessarily interrelated, sources (multisource). Some types of surface data may be correlated with one another and with other types of remote sensing data (multiphase).

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It is evidently clear that the environmentalist is an important player in gathering, and verifying, such data. One should not view the use of satellite imaging as supplanting the time-tested environmental assessments and recordings we have learned for years.

SPACE SATELLITE INFRASTRUCTURE AND ORGANIZATION

A final piece in the use of imaging in environmental exploration is the perspective of space-satellite systems. A complete space system consists of five different segments to be fully functional. They are the:

- Space segment (the satellite you want to launch and orbit for exploration);
- Ground segment (the common user or mission unique system where you talk to satellites);
- Communications (the means for talking between the space and ground segments);
- Launch segment (the rocket to put your satellite into orbit); and
- User segment (the people funding the segment and desiring data gathered by your satellite).

One can see that this space-based enterprise of remote sensing is an expanding "industry" and sponsored government initiative. Not only in the United States but also throughout the world. While many of these segments are completely operational for military systems; today they provide more information to the general public, easily accessible over the World Wide Web network. The use of satellite data for disaster analysis and planning of relief for injured individuals or displaced families can be very effective but only if the satellite can acquire imagery almost immediately after the event. In the future, look for the possibility of sensors that can "point" to geographic locations or phenomena while in orbit. Environmentalists, newly acquainted to the use of computer technology in environmental education may now add understanding of space-based technology to obtain a more complete picture of environmental conditions.

As for the schools and teachers, this interdisciplinary endeavor of remote sensing provides a rich natural basis for curriculum planning and learning activities to motivate students and assist education planners in the implementation of Pennsylvania's Environment and Ecology as well as Science and Technology Standards. What is needed is the creative environmental educator to cultivate classroom technology-adapted learning environments.

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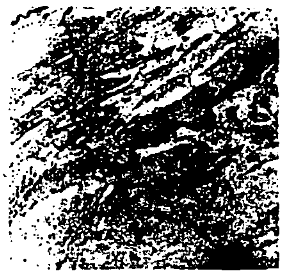
APPENDIX A

Defoliation and Ecological Damage from Mine Wastes

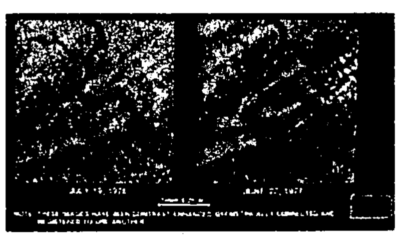
Verbatim text from The Remote Sensing Tutorial
Section 3: Vegetation Applications – Agriculture, forestry, and Ecology

"The next scene points to two modes of ecologic setbacks: massive defoliation of trees and despoilment of the landscape by uncontrolled waste disposal of coal mine tailings. Both are displayed side by side in this MSS Band 7 Landsat image of central Pennsylvania:



Taken on June 8, 1977, the image is bisected by the Susquehanna River as it flows into the Chesapeake Bay (bottom). Very dark blotchy areas in the lower central half include the towns of Lancaster, York, and Gettysburg. The upper left 40% is dominated by the tightly folded ridges of the Appalachian Fold Belt (see second full scene in Section 6); these show up a light grays (high reflectances) in this IR band. Just south of where the Susquehanna cuts through the anticline making up Blue Mountain lies the state capital at Harrisburg (identified in part by two thin black lines radiating eastward). In the Lebanon Valley to its east, some of the farmlands are discernible as blackish spots: these are fields in such early stages of planting that dark soils still dominate.

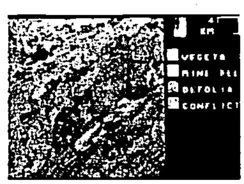
Look at the ridges north of Harrisburg. There are extensive segments of dark gray tones that bespeak of absence of reflective foliar leafing. This indeed is the absence of foliage, caused in this case by extensive removal by the widespread infestation of the Gypsy Moth that affected much of the Northeast U.S during the summer of 1977. The extent of this problem can be appreciated by comparing a late June, 1977 scene with one in July, 1976:



Patches of grayish-black, related to the ground showing through the stripped trees, in the 1977 scene are absent in the 1976 scene, when normal full leafing is displayed in uniform reds. Landsat imagery proved a major economic boon to the Pennsylvania Dept. of Environmental Resources for monitoring the localization of moth damage across the state. To assess the extent of defoliation by conventional means, i.e., aerial photoreconnaissance would have cost in excess of a million dollars. But, reliance on just 16 Landsat scenes taken from May to July, purchased at $4000 each and processed for even less, provided all necessary details as to gypsy moth effects, allowing quick response spraying of those areas where the insects were most active.

Refer to the Band 5 image again. In the top center are some very dark elongate patches that seem to lie between ridges. These are spoil banks in valleys within the anthracite coal belt, site of the high quality coal mined for more than 100 years in northeaster Pennsylvania. The banks consist of rock waste and coal lumps and dust, which produce dark surfaces (actually, on the ground this rubble is not too offensive to the eye, as vegetation has moderated its appearance); the waste comes both from underground and surface strip mining. An area near the top right of the Landsat scene is shown in color here as an enlargement:

In this subscene, the Lehigh River cuts across the upper right and Interstate 81 runs past the town of Hazleton in the upper left. Areas covered by coal waste are rendered in dark blue; other areas in dark grayish-blue are gypsy moth defoliation patches. These similar appearing surface scars can be distinguished by supervised classification, as shown here:



Thus, not only can Landsat efficiently monitor transient ecological maladies such as insect defoliation but, rather like our clear-cutting examples, can follow long term changes in resource utilization such as strip mining and progress of land reclamation."

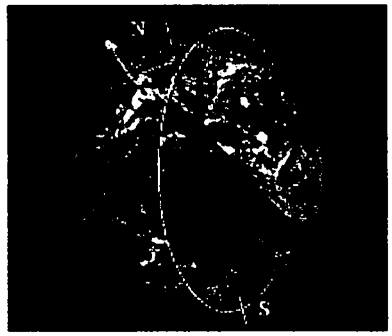


Figure 1. Characterization of POES orbit.

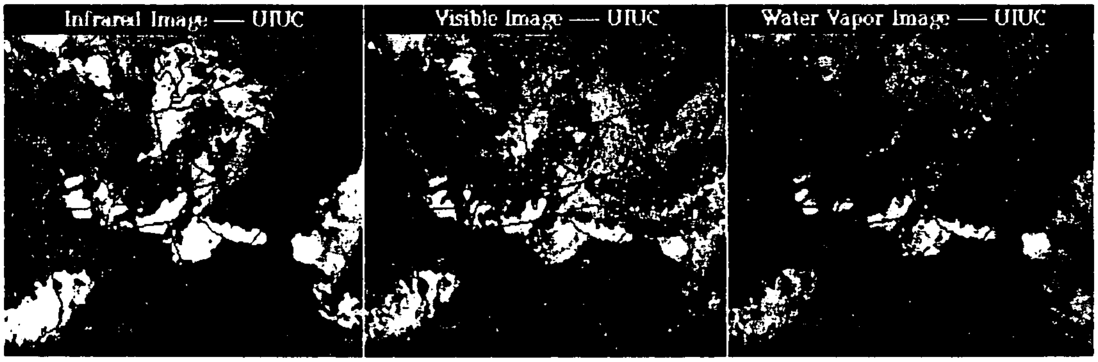


Figure 2. NOAA 14 satellite transmission showing side-by-side placement of IR, visible, and water vapor images.

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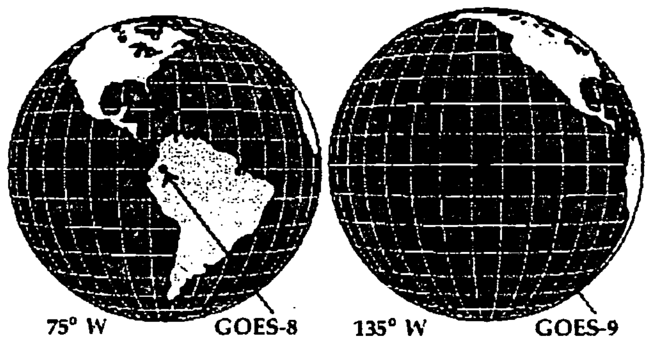

Figure 3. Characterization of GOES positioning in degrees west longitude at the equator.

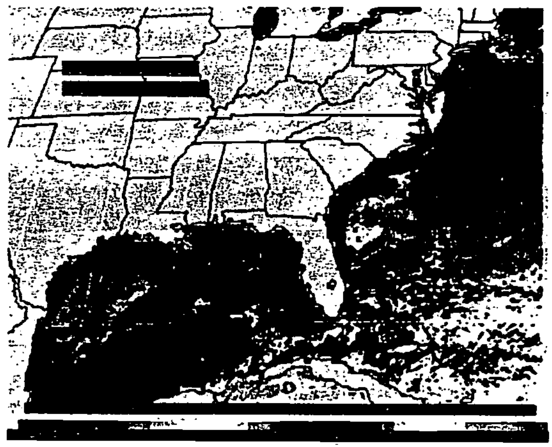

Figure 4. Sea surface temperature composite 19 January 1998.

Table 1. Introductory Signature Key

Color	Land Use/Feature	Texture, Shape, Patterns, ...
Extensive light-toned regions	Mining and construction sites	Isolated road networks
Fairly light-toned regions	Utilities (power lines)	Straight, often not matching alignment of other linear features; may cross roads or run across hills.
White	Snow, clouds, beaches, surf	Snow-covered regions often have visible surface features. Clouds generally have black area beside them, which are their shadows on the ground. Beaches and surf appear as a white strip along coastline between water and vegetated land.
White to bluish	Commercial and industrial services	Features following major roads; large buildings (warehouses, factories, malls, etc.) may be visible as rectangular shapes
White to light blue	Industrial	Straight boundaries. Large buildings may be visible. Much bare ground. Usually outside central urban region. Straight boundaries. Large buildings may be visible. Much bare ground. Usually outside central urban region.
Light blue	Strip development and	Blotchy sections along roads. Isolated from other urban regions
Gray	Residential housing	Blotchy sections surrounding commercial regions. Street patterns may be visible.
Light blue to blue gray	Urban	Little vegetation, highly developed. Roads often seen leading from urban center
Light to dark blue or dark green/black	Cropland or pasture, after harvest, left bare, or in winter	Large covered land areas, tend to have straight boundaries. Curved boundaries near rivers.
Light blue to black	All bodies of water, natural and man-made	Color depends upon the amount of suspended sediment; the greater the amount, the lighter the color the color.
Dark blue to black	Lava flows	Seen leading from volcanic vents. Often on mountain slopes spreading from a central region.
Dark green/black	Wetlands (swamps, marshes) or vegetated areas on wet or submerged land	Vegetated regions on wet ground or shallow water. Along edge of rivers, lakes, bays
Dark Red to Orange	Trees and shrubs	Follows shape of rivers, covering hills and lowlands, usually with a rough texture
Bright red or red-yellow	Deciduous forest in spring, bare in winter	Follows rivers, occupies hilly or low mountainous land. Mixed in with cropland in rural regions.
Brownish-red or purple-red (magenta)	Coniferous forest (evergreens)	Often on higher mountain slopes, separated from lowlands by deciduous forest.
Red to pink	Cropland/pasture, early in the growing season	Large covered land areas, tend to have straight boundaries. Curved boundaries near rivers.
Light pink	Cultivated lawns (parks, golf courses)	Golf courses have a "fingered" appearance. Lawns and parks have rectangular shapes.

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